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GLOBAL CLASSIFICATION OF SONIC LOGS

CROSS REFERENCE TO RELATED APPLICATIONS

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This application is related to co-owned U.S. Patents Numbers 4,809,236, 5,661,696; 5,594,706; 5,587,966; and 5,278,805, and U.S. patent application numbers 09/591,405, now U.S. Pat. 6,625,541, and 09/678,454; now U.S. Pat. 6,459,993, and PCT/IB00/00353, the complete disclosures of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

This invention relates to sonic well logging used in the hydrocarbon well exploration. More particularly, the invention relates to methods for processing sonic well log waveforms.

Sonic logging of wells is well known in hydrocarbon exploration. Sonic well logs are generated using sonic tools typically suspended in a mud-filled borehole by a cable. The sonic logging tool typically includes a sonic source (transmitter), and a plurality of receivers (receiver array) that are spaced apart by several inches or feet. It is noted that a sonic logging tool may include a plurality of transmitters and that sonic logging tools may be operated using a single transmitter (monopole mode), dual transmitters (dipole mode) or a plurality of transmitters (multipole mode). A sonic signal is transmitted from the sonic source and detected at the receivers with measurements made every few inches as the tool is drawn up the borehole. The sonic signal from the transmitter enters the formation adjacent to the borehole and part of the sonic signal propagates in the borehole.

Sonic waves can travel through formations around the borehole in essentially two forms: body waves and surface waves. There are two types of body waves that travel in formation: compressional and shear. Compressional waves, or P-waves, are waves of compression and expansion and are created when a formation is sharply compressed. With compressional waves, small particle vibrations occur in the same direction the wave is traveling. Shear waves, or S-waves are waves of shearing action as would occur when a body is struck from the side. In this case, rock particle motion is perpendicular to the direction of wave propagation.

processing model waveforms with the STC techniques and comparing the measured slowness with the formation shear slowness of the model.

A second technique to provide slowness logging which accounts for dispersion is known as Dispersive Slowness Time Coherence (DSTC) processing or Quick DSTC (QDSTC) and presented in US 5,278,805, the contents of which are incorporated herein by reference. DTSC processing broadly comprises back-propagating detected dispersive waveforms in the Fourier domain while accounting for dispersion and then stacking the processed waveforms. DSTC processing has the ability to be applied to non-dispersive waves such as monopole compressional or shear waves. Since the first step required for DSTC processing is the calculation or selection or an appropriate dispersion curve, all that is required is a dispersion curve that represents a non-dispersive wave, i.e., a flat "curve".

The first step in slowness-time coherence processing is computing semblance, a two-dimensional function of slowness and time, generally referred to as the STC slowness-time plane. The semblance is the quotient of the beamformed energy output by the array at slowness p (the "coherent energy") divided by the waveform energy in a time window of length T (the "total energy"). The semblance function is given by Equation (1) where $x_i(t)$ is the waveform recorded by the i-th receiver of an M-receiver equally spaced array with inter-receiver spacing ΔZ. The array of waveforms $\{x_i(t)\}$ acquired at depth z constitutes a single frame of data.

$$\rho(\tau,p)=\frac{\int_{\tau}^{\tau+T}\left[\sum_{i=0}^{M-1}x_i(t+i\Delta zp)\right]^2 dt}{M\int_{\tau}^{\tau+T}\sum_{i=0}^{M-1}\left[x_i(t+i\Delta zp)\right]^2 dt} \qquad (1)$$

The semblance $\rho(\tau,p)$ for a particular depth z is a function of time τ and slowness p.

A second step is identifying peaks corresponding to high coherence on the slowness-time plane. Peaks are identified by sweeping the plane with a peak mask. The peak mask is a parallelogram having a slope that corresponds to the transmitter-receiver spacing. A peak is defined as a maximum within the mask region. For each peak, five variables are recorded: the

slowness coordinate p, the time coordinate τ, the semblance $\rho(\tau,p)$, the coherent energy (the numerator of Equation 1), and the total energy (the denominator of Equation 1).

Peaks in coherence values signify coherent arrivals in the waveforms. For each depth, a contour plot of coherence as a function of slowness and time, referred to the slowness-time plane, can be made. Classification occurs when the slowness and arrival time at each coherence peak are compared with the propagation characteristics expected of the arrivals being sought and the ones that best agree with these characteristics are retained. Classification involves identifying time-slowness peaks as a particular waveform arrival. Classifying the arrivals in this manner produces a continuous log of slowness versus depth.

A "track" is defined by a sequence of measurements over depth and "tracking" involved associating measurements made at one depth with measurements made at other depths. Typically in prior art methods the slowness and arrival time at each coherence peak are compared with the propagation characteristics of the expected arrivals and classified as to type of arrival and "labeled" or "tracked" as corresponding to compressional (P-wave), shear (S-wave) or Stoneley waveform arrivals. Thus classified, the arrivals produce a continuous log of slowness versus depth, referred to as a "track", a sequence of measurements composed of peaks identified as belonging to the same arrival as shown in FIG. 2. Referring to FIG. 2, peak **20** is classified as a compressional arrival and peak **22** is classified as a shear arrival and the classified peaks are joined to other arrivals of the same waveform in a slowness versus depth log. In prior art methods, the tracking composed two distinct steps 1) joining the peaks corresponding to the same waveform arrival in the track-search step to compose a "track", and 2) identifying the tracks by a name through classification of the tracks. In these methods, individual peaks required classification independent of the tracks.

Correct tracking of the peaks is a difficult process for a number of reasons. Some of the peaks may correspond to spatial aliases rather than the arrival of real waveforms. Some of the peaks may actually be two peaks close together. In general, a shortcoming with prior art methods for tracking is that small changes in sonic waveform data can cause large differences in the final classification.

In a classification method referred to as local classification and described in US Patent Application No. 09/591,405 (hereinafter '405), the peaks are classified by referring to only two levels, the current level and the previous level. This local classification of peaks of the tracks is independent of other non-adjacent peaks. Such a classification, because of the limits of the Bayesian algorithm used, does not classify the whole track but just the adjacent peaks of the